

## Study of Semiconducting Behaviour of Be at Low Temperature

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### ABSTRACT

We have analysed the variations of electrical resistance data of Be with temperature and found that it is more or less a semiconductor at very low temperature. The high value of electrical resistivity and its temperature independent of Be at low temperature suggests that the metal is virtually a semiconductor at low temperature. It also behaves as semiconductor even up to 90K.

**Keywords:** Electrical resistance, Semiconductor, Semimetal, Impurity Content, lattice defect, residual resistivity, Insulators, Hall Coefficient.

### 1. INTRODUCTION

Electrical resistivity is one of basic parameter which differentiates metals, semimetals and semiconductors. The parameter consists of so many other parameters like electron density, impurity content and lattice defect etc. At low temperature lattice defects and impurity cause in limiting the mean free path of electron in metals but the resistance caused by them is practically constant and independent of temperature. The ideal electrical resistivity caused by lattice vibrations is strongly the temperature

dependent and it varies as  $T^5$  <sup>[1]</sup> but its contribution relatively is very small in comparison to residual resistivity caused by impurities and lattice defects even in purest sample of metal. Experiments <sup>[2-5]</sup> do not find it more than 15% of the total resistivity in any case.

At low temperature, anharmonicity of lattice waves is supposed to be weak <sup>[6,7]</sup> and the Debye's model is used faithfully. There is some chance of deviation of energy spectrum of phonons from Debye's model due to presence of impurity and lattice defect which enhance the anharmonicity of lattice waves<sup>8,9</sup>.

In a pure specimen of metal, this effect however may be reduced. On the whole the low temperature zone is suitable for the test of theory of electrical resistivity of metals. In semiconductors, the impurity plays an important role. It dominates in contributing the electrical conductivity of a semiconductor. Therefore, the theory of electrical resistivity of metals can not be applied to the electrical conductivity of a semiconductor<sup>8,10</sup>.

Thus analysis of the electrical conductivity of solid will classify them in to metals and semiconductors at low temperatures. The electrical resistivity of metals become linear function of temperature, however, in the semiconductors it is the exponential function of temperature<sup>[8,10]</sup>. This result is helpful in distinguishing the metals from the semiconductors and insulators.

In solid both the electrons and phonons are supposed to carry thermal energy in presence of temperature gradient. In metals the electronic contribution dominates over the phonon contributions at low temperature. In semiconductors both contributions are of comparable magnitude. The magnitude and temperature variation of thermal conductivity vary in different kinds of solids viz. metals, semiconductors & insulators. Hall coefficient gives the accurate information about the different type of conductors i.e. metals and semiconductors on the basis of nature of charge carriers and density of charge carriers<sup>10,11,8</sup>.

## 2. THEORETICAL DISCUSSION

At very low temperature.  
 $T \leq 0.077\theta$

The B.G. formula may be reduced to<sup>12</sup>,

$$\frac{\rho_T}{\rho_\theta} = \frac{497.6}{\theta^5} T^5 \quad (1)$$

At temperature,  $t \leq 0.166\theta$ , the B.G. formula is written as<sup>13</sup>,

$$\frac{\rho_T}{\rho_\theta} = 1.1789 (T/\theta) - 0.16636 \quad (2)$$

Here  $\theta$  = Debye's temperature.

The specific heat at low temperature of metals is found to fit the equation.

$$C_v = \gamma T + BT^3 \quad (3)$$

$$\text{where } \gamma = \frac{\pi^2 \kappa^2}{2\mu_0} \text{ and } \mu_0 = \frac{h^2}{2m} \left( \frac{3n}{8\pi} \right)^{2/3}$$

Here  $\gamma T$  term is interpreted as electronic contribution where  $BT^3$  is the lattice contribution. In semiconductor and insulator at low temperature  $\gamma T$  should be absent. In this way the presence and absence of  $\gamma T$  term distinguishes the metals from the semiconductors and insulators.

For free electrons, the Hall Coefficient  $R_H$  is obtained as<sup>10,8</sup>.

$$R_H = -\frac{1}{nec} \quad (4)$$

where  $n$  is the density of electrons per unit volume,  $e$  is the electronic charge and  $c$  is the velocity of light.

In metals " $n$ " is of the order of  $10^{22}$  and in semi-metals it ranges from  $10^8$  to  $10^{20}$ . Naturally Hall Coefficient of semi-metal is much greater than that of metals. For semiconductors  $R_H$  is obtained as

$$R_H = \pm \frac{3\pi}{8} \left[ \frac{1}{nec} \right] \quad (5)$$

these elements show the semiconducting behaviour of Be.

In case of semiconductors "n" is still lower than that of semi-metals. Value of "n" in degenerate semiconductor is greater than that in non-degenerate semiconductor. In both metals and semi-metals  $R_H$  is constant and is of negative (-) sign as given by theory.

In semiconductors  $R_H$  may have both positive and negative Hall Coefficient corresponding to hole and electrons as charge carriers.

### 3. RESULTS AND DISCUSSION

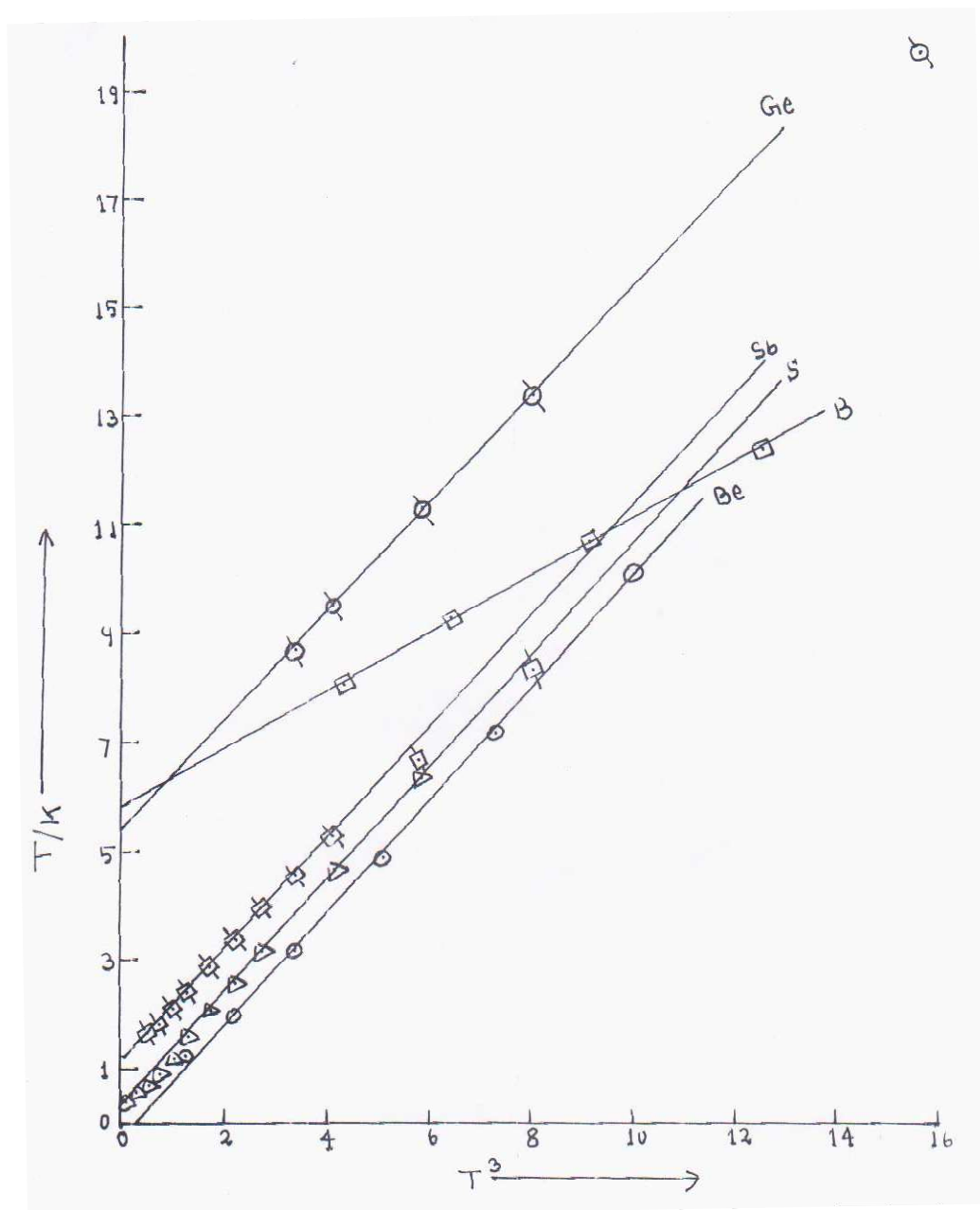
Observed value of the thermal conductivities<sup>[14]</sup> of Be with semiconducting materials are compared. We have plotted T/K against  $T^3$  in case of a specimen Be.

The plots are straight line curve shown in Fig (1). The slope intercept and correlation factor ( $\gamma$ ) of the curve in Fig (1) obtained by least square method is reported in Table (1). We have analyzed the observed thermal conductivity data of semiconductors viz. Ge, Sb, B in the light of electronic contribution. The plots between T/K and  $T^3$  are straight line curve [Fig (1)]. More ever the thermal conductivity of Ge, Sb and B are linear below 10K, 12K and 14K respectively. All these results are similar to the specimen of Be. The nature of graph of

**Table 1 : Slopes, intercepts and correlation factor of the curves between T/K~ $T^3$ .**

Metals	Correlation factor	Slope $\times 10^{-5}$	Intercept	Temperature zone in K
Be	0.9993	1.0045	-0.0797	$45 \leq T \leq 100$
Ge	0.9982	8.9100	0.5934	$15 \leq T \leq 25$
Sb	0.9924	91.7308	1.3228	$8 \leq T \leq 20$
B	0.9994	5.1380	6.0016	$35 \leq T \leq 50$

From the observation of above graph and result it is seen that in the lowest temperature zone the resistivity decreases from Be to Ba in alkaline earth metals. It suggests that the semiconducting behaviour of Be remains in the lowest temperature range and in the case of Ba it is also in the shortest temperature zone<sup>15,16</sup>.



**Fig.1 Plots between  $T/K$  and  $T^3$  of insulators (Se, Ge, S, B and Sb)**  
 [The scales and origin have been suitably altered to portray the desired shapes of the curves ].

#### 4. CONCLUSION

The high value and nearly temperature dependence of electrical and thermal conductivity of Be at low temperature suggests that the alkaline earth-metal is similar as semiconductors. It also behaves as semiconductor even upto 90K.

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